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Estimation of Height from the Length of Long Bones in a Portuguese Adult Population

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KEY WORDS forensic anthropology; stature determination; human skeletal remains

ABSTRACT Research was undertaken on 200 individuals (100 males and 100 females) from the northern districts of Portugal, all Caucasian, between the ages of 20 and 59. Height and bones were measured directly. Estimation of stature is obtained by applying a mathematical method based on a multivariable linear regression between the height of the cadaver and the lengths of humerus and femur. Humerus is measured on full length; femur is measured on both physiological and maximum lengths. Regression formulae and tables for males and females are produced for application in forensic anthropology when studying human skeletal remains. Comparisons are made between these tables and those of earlier authors, allowing us to verify important differences. One of the conclusions concerns the application of regression formulae based on some segment measurements. Due to the extremely high values of standard deviations, these may have no practical application. Am J Phys Anthropol 112:39–48, 2000. © 2000 Wiley-Liss, Inc.

Reconstruction of stature by way of measuring long bones has an established practical application in forensic identification. Earlier reports from Snow et al. (1971), Himes et al. (1982), Pheasant (1988), Giles et al. (1991), Willey et al. (1991), Tambs et al. (1992), Mendonça et al. (1994), and Langaney (1994) show that a person's stature is an extremely variable biological parameter. According to Pheasant (1988) and Langaney (1994), it may vary, even with the same person, throughout the day. Studies from Trotter and Gleser (1951a), Miall et al. (1968), Hertzog et al. (1969), Trotter (1970), Galloway (1988), Galloway et al. (1990), and Giles (1991) show that it may vary with age and, according to Brothwell (1981) and Lundy (1988b), even with certain illnesses and anomalies; it may vary, as well, from person to person between different populations, as other reports from Brothwell (1981), Sánchez (1984), Pheasant (1988), Langaney (1994), and Cohen (1995) reveal.

In spite of the above variations, studies by Villanueva-Cañadas et al. (1991) reveal that there is a well-defined relationship between the height of a person and the length of his or her long bones. This allows us, according to Arbenz (1983) and Himes (1989), to calculate the stature of an individual from the measurement of these bones. It is also possible to calculate the height which an individual had in life, through data obtained from a corpse, although the stature of the living person and of its corpse differ by about 2 cm, as earlier reports from Manouvrier (1892, 1893), Trotter and Gleser (1952, 1958), and Trotter (1970) reveal.

Since the beginning of the century, numerous studies have endeavored to improve the calculation of height derived from mea-

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surement of long bones. In all these studies, the lack of well-documented recent skeletal material has been a limiting factor, in part because of the secular trends, in height (Iscan, 1988; Trotter and Gleser, 1951b).

There are two basic methods for calculating height from skeletal remains. The mathematical method, based on a proportionality between height and the length of long bones (Knight, 1991), and the anatomical method, based on the measurement of the whole skeleton, including the spinal column, and adding the dimensions of the soft parts, as presented by Dwight (1894), Fully (1956), Fully and Pineau (1960), and Lundy (1985, 1988a). The method mostly used is some version of a mathematical model.

Calculation of height is an indispensable step in any forensic anthropological investigation of adults and should be done after determining the sex of the individual. Choice of the regression formulae or the consulting tables must be specific to the basic biological profile of the individual.

Of all studies published, the tables of Trotter and Gleser (1952, 1958), in the United States, and those of Manouvrier (1892, 1893), in Europe, are by far the most consulted. In Portugal, as well as in Spain, the determination of stature from long bones of skeletal remains has been based on these two published works, as confirmed by Reverte-Coma (1991). However, these tables are based on skeletal data which differ temporally, as well as genetically, from those most frequently encountered in modern Portugal (Reverte-Coma, 1991; Villanueva-Cañadas et al., 1991).

MATERIALS AND METHODS

Our investigation is based on the study of corpses autopsied at the Medico-Legal Institute of Oporto. These cadavers, 100 males and 100 females, are, in the majority, of Portuguese nationals, who lived in the northern regional districts of this country.

Cause of death of the cadavers studied was not taken into consideration. What was considered, in all cases, was that the body be free of any skeletal pathology that could preclude accurate measurement. All cadavers with skeletal deformities, amputations or atrophies of members were excluded, as well as individuals with cranial, vertebral, or extremity trauma.

All the subjects studied are European from the Iberian Peninsula. Selection was based on anthropomorphic criteria and on the identification of each individual (filiation and place of birth). Excluded, therefore, independently of nationalities, were all individuals of obvious non-native Portuguese ancestry in order to obtain a sample as homogeneous as possible.

Only individuals between the ages of 20 and 59 (inclusive) were included in this research. In this study, the average age of men was 38.1 years and of women 37.2 years. No correction of height due to age was made.

To measure cadaveric height, we used a metallic bar graduated in centimeters, with one end set and the other mobile, normally used in the morgue of the Medico-Legal Institute of Oporto, expressly for this effect. Cadavers were measured after being placed in the prone position, on an autopsy table. This measurement was made before autopsy to avoid alteration of the cadaver. Measurement of stature of the cadaver was taken as the distance from the top of the skull to the heel. This measurement was obtained in centimeters and denominated T_c.

Height of the bodies was measured directly in all cases. Real height, when alive, according to Trotter and Gleser (1952, 1958) and Trotter (1970), will correspond to the height of the cadaver less 2.35 cm, since the intervertebral discs will be flattened when the subject is standing up, as studies by Pheasant (1988) reveal. For this work, we only obtained height in centimeters, since the graduated metallic bar used did not allow for precision in millimeters.

Thus, considering the height of the cadaver T_c (in centimeters), estimated height while alive is $T_c - 2$ (Fig. 1). These latter values were used for all statistical considerations. From now on whenever we refer to "height" we are referring to $T_c - 2$.

The long bones measured were the humerus and the femur of the right side. Bones were removed from the cadaver, usually after the autopsy. The skin was incised by scalpel, lengthwise, along the arm (inside or outside faces) and the thigh (side or be-

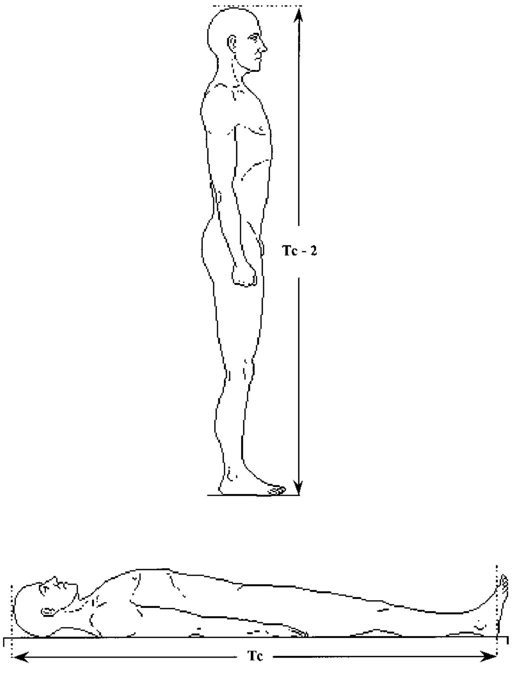

Figure 1. The height while alive ($T_c - 2$) is shorter by 2 cm to the height measured in the corpse (T_c).

hind faces); then the subcutaneous tissue and underlying muscles were also cut. The bone was disarticulated. Once separated, the soft tissue (muscles and tendons) was removed. Care was taken to avoid disfigurement of the cadaver and to avoid damaging the bone as much as possible.

The full length of each bone was measured with cartilage over the osteometric table, in millimeters. The distances of the parameters of segments, which will be defined later, were measured with a ruler, also in millimeters. All measurements were taken by the author.

After measurement, each bone was replaced in the corpse and secured by suturing. We are conscious of the ethical and humane questions which the use of corpses in scientific investigation may raise (King et al., 1995). Thus, it was always our obligation that the corpse, upon leaving the Medico-Legal Institute of Oporto and being handed over to its family, should never seem mutilated nor disfigured. Ethical and legal factors were always complied with.

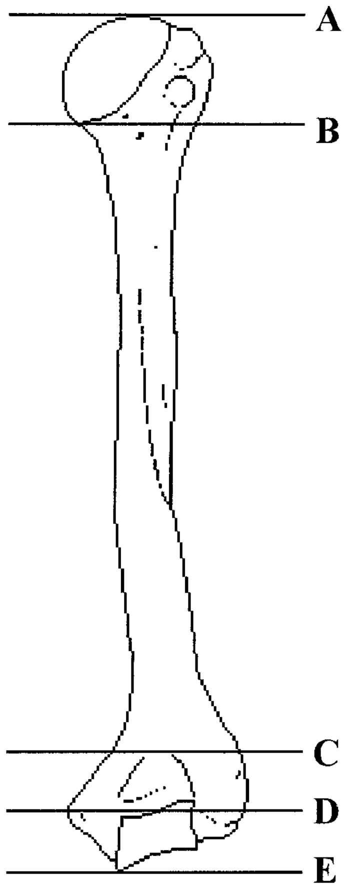

Figure 2. Humerus: distances A–E, A–B, C–D, D–E, and C–E.

Description of the points of measurement

Humerus. To obtain total length, the bone is placed in an osteometric table over its anterior face, with the olecranon fossa uppermost and perpendicularly aligned to the ends of the table. Total length is measured from the most proximal point of the head to the most distal point of the trochlea (Fig. 2, distance A–E). Segments are measured along the longitudinal axis of the bone.

Humeral head. Following the longitudinal axis of the bone, this distance is measured between the most proximal point of the head and a line passing through the most distal portion of the articular surface of the head (Fig. 2, distance A–B).

Olecranon cavity. This distance is measured along the longitudinal axis of the bone between the most proximal point and the most distal point along the edges of the olecranon cavity (Fig. 2, distance C–D). The proximal border is marked by the transition between the smooth surface of the posterior face of the distal epiphysis and the beginning of the cavity. The distal edge is the transition line between the wrinkled surface of the olecranon fossa and the smooth surface of the trochlea.

Trochlea. This distance is measured along the longitudinal axis between the more distal point of the olecranon cavity and the most distal point of the trochlea (Fig. 2, distance D–E).

Distal extremity. This distance is measured along the longitudinal axis between the most proximal point of the olecranon cavity and the most distal point of the trochlea (Fig. 2, distance C–E). This is the sum of the two previous measurements.

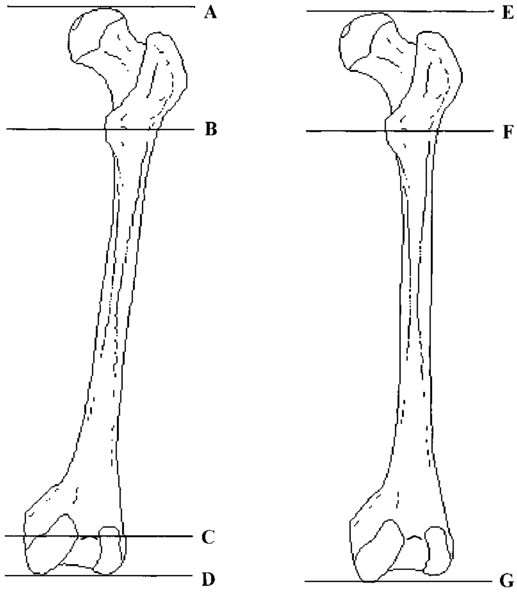

Figure 3. Femur: distances A–D, A–B, C–D, E–G, and E–F.

Femur. For physiological length (oblique or bicondylar) the bone is placed on the table over its anterior face, that is, with the popliteal surface toward the observer. Physiological length is measured from the most proximal point of the head to a line passing through the most distal points of both condyles (Fig. 3, distance A–D). Segments A–B and C–D are measured while the bone is positioned for physiological length. For perpendicular length (maximum), the bone is also placed on the measuring board on its anterior face with the popliteal surface toward the observer. This length is measured from the most proximal point of the head to the most distal of the medial condyle (Fig. 3, distance E–G). Distance E–F is measured along the longitudinal axis.

Proximal extremity with the femur in an oblique position. This measurement is the distance between the most proximal point of the head and the midpoint of the lesser trochanter, while in physiological position (Fig. 3, distance A–B).

Distal extremity. It is the distance between the intercondilian line and the plane which passes through the most distal points of both condyles, in physiological position (Fig. 3, distance C–D).

Proximal extremity with the femur in a perpendicular position. This distance is measured along the longitudinal axis of the bone. This measurement is the distance between the most proximal point of the head and the midpoint of the lesser trochanter (Fig. 3, distance E–F).

Mathematical method

Simple linear regressions, multivariable and by groups, for each sex and for each bone, in accordance with earlier studies by Giles et al. (1988), Albrecht et al.(1993), and Sokal et al. (1995), were produced. The resulting formula gives us an estimation of height (y), from each measurement of the bone length (x). This regression formula is the one we applied for groups of each sex and for each length of the bone. Statistical analysis was performed using BMDP Statistical Software, from the Centro de Cálculo of the Complutense University of Madrid.

TABLE 1. Descriptive linear regression of whole sample (n = 200)

Variable[1]	Mean	Standard deviation	Coeficient of variation	Minimum	Maximum
STAT (cm)	160.8	8.32	0.05175	143	183
FLH (mm)	312.2	20.51	0.06570	265	368
PhLF (mm)	429.3	27.44	0.06392	371	497
PLF (mm)	431.5	27.53	0.06379	373	498

[1] STAT = stature, FLH = full length of the humerus, PhLF = physiological length of femur, PLF = perpendicular length of femur.

RESULTS

The height of cadavers, in the male sample, varied between 153 and 185 cm, the mean height being 167.9 cm. In women these values varied between 145 and 175 cm, the mean height being 157.7 cm.

Estimation of stature from the total length of the bones

The first step toward the statistical handling of data was the study of variation in height in relation to the total lengths of the bones. A multivariable linear regression in the total sampling, that is, for both sexes and bones, was calculated and then the simple linear regression by groups, for each sex and for each bone.

We considered, as a dependent variable, the estimated height (STAT) in centimeters and as independent variables the lengths of bones, in millimeters, that is: the full length of the humerus (FLH), the physiological length (oblique or bicondylar) of the femur (PhLF) and the perpendicular length (maximum) of the femur (PLF) (Table 1).

The research was undertaken with a tolerance of 0.01 ($P < 0.05$).

Upon analyzing the variation for each length and for each sex, we obtained, in the six analyses, acceptable predivisible residual values, except in certain cases. Thus, we decided to eliminate those cases in which the residual value was greater than 2 standard deviations, that is, more than 9 cm.

In this way, we repeated all the linear regressions with a sample of 191 cases (95 female and 96 male).

Regression formulae obtained for each sex and for each length of bone are presented in Table 2. The equation between brackets produces the predictive height and is followed by the 95% confidence interval.

TABLE 2. Determination of stature from the length of long bones[1]

Females—regression formulae
STAT = [64.26 + 0.3065 FLH] ± 7.70
STAT = [55.63 + 0.2428 PhLF] ± 5.92
STAT = [57.86 + 0.2359 PLF] ± 5.96
Males—regression formulae
STAT = [59.41 + 0.3269 FLH] ± 8.44
STAT = [47.18 + 0.2663 PhLF] ± 6.90
STAT = [46.89 + 0.2657 PLF] ± 6.96

[1] STAT = stature we pretend to estimate (cm), FLH = full length of the humerus (mm), PhLF = physiological length of the femur (mm), PLF = perpendicular length of the femur (mm).

Consulting tables were created based on the regression formulae. The predicted heights were drawn up according to sex (females in Table 3, males in Table 4). It is always necessary to attribute a confidence interval on the value of average estimated height, which is specific for each bone and each sex.

Estimation of height from data of measurement of segments

The second step in this research consisted in the study of variations in height in relation to the measurement of segments. To this end, we undertook a multivariable simple linear regression between the full lengths of each bone and the value of some distances of segments, suggested by Steele and McKern (1969).

We considered, as dependent variables, the lengths of bones, in millimeters [the full length of the humerus (FLH), the physiological length (oblique or bicondylar) of the femur (PhLF), and the perpendicular length (maximum) of the femur (PLF)]. As independent variables, in millimeters, we considered:

TABLE 3. Consulting table for females

Humerus full length (mm)	Mean height (cm)	Femur	
		Physiological length (mm)	Perpendicular length (mm)
247	140	347	348
250	141	352	352
254	142	356	357
257	143	360	361
260	144	364	365
263	145	368	369
267	146	372	374
270	147	376	378
273	148	380	382
276	149	385	386
280	150	389	391
283	151	393	395
286	152	397	399
290	153	401	403
293	154	405	408
296	155	409	412
299	156	413	416
303	157	418	420
306	158	422	425
309	159	426	429
312	160	430	433
316	161	434	437
319	162	438	441
322	163	442	446
325	164	446	450
329	165	450	454
332	166	455	458
335	167	459	463
338	168	463	467
342	169	467	471
345	170	471	475
348	171	475	480
352	172	479	484
355	173	483	488
358	174	488	492
361	175	492	497
365	176	496	501
368	177	500	505
371	178	504	509
374	179	508	514
378	180	512	518

TABLE 4. Consulting table for males

Humerus full length (mm)	Mean height (cm)	Femur	
		Physiological length (mm)	Perpendicular length (mm)
277	150	386	388
280	151	390	392
283	152	394	396
286	153	397	399
289	154	401	403
292	155	405	407
295	156	409	411
299	157	412	414
302	158	416	418
305	159	420	422
308	160	424	426
311	161	427	429
314	162	431	433
317	163	435	437
320	164	439	441
323	165	442	445
326	166	446	448
329	167	450	452
332	168	454	456
335	169	457	460
338	170	461	463
341	171	465	467
344	172	469	471
347	173	472	475
351	174	476	478
354	175	480	482
357	176	484	486
360	177	487	490
363	178	491	493
366	179	495	497
369	180	499	501
372	181	503	505
375	182	506	509
378	183	510	512
381	184	514	516
384	185	518	520
387	186	521	524
390	187	525	527
393	188	529	531
396	189	533	535
399	190	536	539

For FLH:

- distance A–B (head), termed H1
- distance C–D (olecranon cavity), termed H2
- distance D–E (trochlea), termed H3
- distance C–E (distal extremity), termed H4

For PhLF:

- distance A–B (proximal extremity with the femur in a physiological position), termed F1
- distance C–D (distal extremity), termed F2

For PLF:

- distance E–F (proximal extremity with the femur in a perpendicular position), termed F3

All these parameters were considered as a simple group. The study was undertaken with a tolerance of 0.01 ($P < 0.05$). We also undertook a simple linear regression, multivariable and by groups, in the total sampling, that is, for both sexes and, separately, for each sex and each measurement of segment.

In both sexes, the results obtained, produced such large standard errors, that the

TABLE 5. Linear regression, in both sexes, for segment lengths (n = 200)

Variable	Mean	Standard deviation	Coeficient of variation	Minimum	Maximum
FLH (mm)	312.2	20.51	0.06570	265	368
H1 (mm)	37.5	3.95	0.10523	29	48
H2 (mm)	21.0	2.04	0.09732	17	27
H3 (mm)	15.6	2.22	0.14231	11	23
H4 (mm)	36.6	3.00	0.08211	30	46
PhLF (mm)	429.3	27.44	0.06392	371	497
PLF (mm)	431.6	27.53	0.06379	373	498
F1 (mm)	78.4	7.76	0.09908	59	101
F2 (mm)	34.6	3.06	0.08855	27	45
F3 (mm)	75.6	8.0	0.10588	56	98

TABLE 6. Correlation matrix, in both sexes, for segment lengths

	FLH	H1	H2	H3	H4	PhLF	PLF	F1	F2	F3
FLH	1									
H1	0.52	1								
H2	0.37	0.21	1							
H3	0.49	0.64	−0.01	1						
H4	0.61	0.61	0.67	0.73	1					
PhLF	0.88	0.51	0.34	0.48	0.59	1				
PLF	0.88	0.50	0.34	0.47	0.58	0.99	1			
F1	0.52	0.53	0.36	0.43	0.57	0.64	0.63	1		
F2	0.62	0.58	0.35	0.49	0.60	0.61	0.60	0.57	1	
F3	0.50	0.53	0.33	0.45	0.56	0.63	0.62	0.98	0.53	1

TABLE 7. Linear regression and analysis of variance for each segment lengths (females)

	Multiple R	Multiple R-square	Mean square (residual)	Standard error of estimation (S)
H1	0.1005	0.0101	232.3010	15.2414
H2	0.1537	0.0236	229.1290	15.1370
H3	0.2381	0.0567	221.3680	14.8784
H4	0.2934	0.0861	214.4638	14.6446
F1	0.4776	0.2281	369.5448	19.2235
F2	0.3353	0.1124	424.9046	20.6132
F3	0.4624	0.2139	395.9986	19.8997

TABLE 8. Linear regression and analysis of variance for each segment lengths (males)

	Multiple R	Multiple R-square	Mean square (residual)	Standard error of estimation (S)
H1	0.0487	0.0024	261.6433	16.1754
H2	0.3472	0.1206	230.6428	15.1864
H3	0.1663	0.0277	255.0089	15.9690
H4	0.4346	0.1888	212.7395	14.5856
F1	0.4454	0.1984	384.9724	19.6207
F2	0.4270	0.1823	392.6828	19.8162
F3	0.4340	0.1884	389.3271	19.7314

practical application of the method does not seem to have any value (Tables 5–8).

DISCUSSION

This investigation was carried out with a sample of fresh corpses, i.e., non-skeletized bodies, from which it was possible to measure the height directly. The measurement of the length of the bones was also effected directly in each case.

All the work involved in drawing up the regression formulae and the tables was effected basically on heights calculated, following the criterion of Trotter and Gleser (1952), from those measured directly from the corpses. Therefore, the estimated values of height obtained through the application of these methods are values of height while alive and not values of cadaveric height.

Dry bones are slightly smaller than fresh ones. Rollet (1888), more than 100 years ago, established this difference as 2 mm. Taking into account that this present research was based on measurements of fresh bones, this fact should not be forgotten whenever we are dealing with dry bones.

Comparison of our results with the findings of other authors

We compared our tables with those most frequently used in Portugal, that is, with the tables of Manouvrier (1892, 1893) and with those of Trotter and Gleser (1952, 1958). We also compared them with the tables of Telkka (1950), since they are based

TABLE 9. Comparison of our results with the results of other authors (females)

STAT (cm)	Our Results (mm)			Manouvrier[1,2] (mm)		Trotter and Gleser[3] (mm)		Telkka[3] (mm)	
	FLH	PhLF	PLF	Humerus	Femur	Humerus	Femur	Humerus	Femur
140	247	347	348	263	363	244	348	—	—
145	263	368	369	273	378	259	368	263	352
150	280	389	391	282	393	274	388	282	380
155	296	409	412	297	415	289	409	300	408
160	312	430	433	313	436	304	429	319	436
165	329	450	454	329	457	319	449	337	463
170	345	471	475	339	471	333	469	356	491
175	361	492	497	—	—	348	489	374	518
180	378	512	518	—	—	363	510	—	—

[1] The value of heights is approximate, since it is presented in the tables, in the original, in millimeters.
[2] There are no records about the way the bones were measured by Rollet (1888); notice that Manouvrier used Rollet's data to build up his tables.
[3] Both humerus and femur were measured in their maximum length.

TABLE 10. Comparison of our results with the results of other authors (males)

STAT (cm)	Our Results (mm)			Manouvrier[1,2] (mm)		Trotter and Gleser[3] (mm)		Telkka[3] (mm)	
	FLH	PhLF	PLF	Humerus	Femur	Humerus	Femur	Humerus	Femur
150	277	386	388	—	—	—	—	—	—
155	292	405	407	298	398	275	393	278	387
160	308	424	426	309	416	291	414	296	410
165	323	442	445	324	440	307	435	313	434
170	338	461	463	340	467	323	456	331	458
175	354	480	482	352	490	339	477	349	482
180	369	499	501	—	—	356	498	367	506
185	384	518	520	—	—	372	519	385	529
190	399	536	539	—	—	388	540	—	—

[1] The value of heights is approximate, since it is presented in the tables, in the original, in millimeters.
[2] There are no records about the way the bones were measured by Rollet (1888); notice that Manouvrier used Rollet's data to build up his tables.
[3] Both humerus and femur were measured in their maximum length.

on an European population. We found irregular disparities between these studies and ours. Description of the comparison of some values is contained in Tables 9 and 10. The simple descriptive comparison of the data allows us to verify important differences. To ascertain whether these differences are biologically relevant will be risky.

We are certain, as already testified by Camps (1968), Stewart (1973), Knight (1991), and Reverte-Coma (1991), that the application to present populations of tables published some years ago or referring to different peoples may lead to important errors of estimation. Comparing our results with the studies of Mendes-Corrêa (1932), shows that the mean height of the respective samples has increased in both sexes. Mean height of Portuguese peoples has increased, during these last 64 years, by 4 cm in women and 3 cm in men (Table 11). This comparison could be fully explained with more details in future publications.

Estimation of height segment lengths

In forensic anthropology, a method to estimate height based on the distances of segments of long bones is important. In this study, we tested a method based on the proportionality between determined distances among fixed points of bones and their total length. These distances were some of the ones suggested by Steele and McKern (1969), namely, the ones concerning the epiphysis of humerus and femur. With the femur, these distances were measured placing the bone on the osteometric table in both positions, oblique or bicondylar and perpendicular or maximum. Regression results obtained by us do not permit, in any way, their practical application. Values of standard deviations are extremely high, which removes whatever viability the method could have.

The results do not justify the use of this method, and the search for other parameters becomes a pressing matter. Simmons,

TABLE 11. Comparison of the average height of portuguese between 1932 and 1996

	Mendes-Corrêa (1932) (m)	Our Results 1996 (m)
Women	1.52	1.56
Men	1.63	1.66

Jantz and Bass (1990) published a revision of Steele's method for segments of the femur, creating new fixed points based, fundamentally, on the dimensions of the epiphysis. Undoubtedly, this is a process that has to be taken into account in future investigations, even though, it seems to us, that the total length of a long bone will have to be considered more in relation to the distances measured throughout its longitudinal axis, namely, the shaft length, than to the transversal or sagittal measurements of the epiphyses.

CONCLUSIONS

These regression formulae and consulting tables can be applied to peoples from the north of Portugal and, by analogy, to all the peoples of the Iberian Peninsula. The application of these regression formulae and/or consulting tables allows us to determine the height of a living individual from the measurements of the humerus and femur, in skeletal state, as long as the bones are whole.

Should these bones be fragmented, we were unable to obtain a reliable method of determining the measurement of the whole bone and, based on this, calculate the stature of the individual. This failure thus opens new doors for further research.

The humerus must be measured in its full length. The femur may be measured by its physiological length or by its perpendicular or maximum length. Use of the humerus should occur only when the femur is not present or too fragmented for accurate measurement. In effect, the application of this method, using solely the femur, will afford satisfactory results.

It is more correct to apply regression formulae instead of consulting tables, because formulae give us more exact values as regards the calculation of stature, with determined confidence intervals. Consulting tables, drawn up to facilitate obtaining rapid results, do not afford such exact values as regression formulae, but only average and rounded off values. The application of regression formulae needs a good interpretation of confidence intervals. The height obtained, by way of the application of the formula, is the standard estimated height in 95% of the cases. We must not forget, as wisely stated by Brooks et al.(1990), that age at death, sex, and ethnicity can be documented easily, but adult stature rarely has been accurately recorded during life. So estimation of stature should only be considered approximations of the true stature.

Limitations of these results in time and space, nevertheless, allow for their indisputable practical application in the field of forensic anthropology. This was, without any doubt, the great challenge of this study.

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